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The impact of defects on energy performance of buildings: Quality management in social housing developments

João Alencastro[a]*, Alba Fuertes[a], Andrew Fox[b], Pieter de Wilde[a]

[a]*Department of Architecture and Built Environment, Plymouth University, Drake Circus, Plymouth, PL4 8AA, United Kingdom.*
[b]*School of Engineering, Plymouth University, Drake Circus, Plymouth, PL4 8AA, United Kingdom.*

Abstract

Construction defects in the domestic sector, especially occurring in the building fabric, are acknowledged to contribute to the energy performance gap of buildings. Discontinuity of insulation layers, gaps in the vapor/air barriers and thermal bridging through building elements lead to undesired heat loss, and thus to the increase of energy use for space heating. This study set out to investigate how quality management systems related to energy performance of buildings are defined and implemented in social housing projects in the UK. The analysis of evidence collected from a number of Housing Association case studies suggests that in the majority of the projects, the deployed quality management procedures focused on visual quality issues, allowing defects with the potential to impair the thermal performance of the dwellings to remain uncorrected. Despite a range of quality control procedures administered by the client, contractor and independent agents, they did not systematically appraise such defects during the construction stage. Apart from one case study, the quality management systems implemented in the projects lack an objective definition of the compliance methodology when addressing to the energy performance quality criteria.

Keywords: Energy efficiency, building energy, building regulations, quality management, defects, social housing.

1. Introduction

The domestic housing sector is responsible for 25% of the energy use in the UK [1], being 66% of the energy consumed for space heating [2]. As such, any innovations that can reduce space heating requirements in domestic

* Corresponding author. Tel.: +44 1752 585192; fax: +44 1752 585155.
E-mail address: joao.ulrichdealencastro@plymouth.ac.uk

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sector have the potential to significantly impact the UK energy demand. This paper investigates how quality management systems in the UK domestic housing sector are planned and implemented, focusing on energy performance aspects. The study also assesses how quality management system enhancements could be applied to reduce energy demand. In order to reduce energy consumption, scholars and policy-makers have acknowledged that there is a need to improve significantly the energy efficiency of buildings [3, 4]. The UK construction industry has committed to increase the thermal performance in both existing and new buildings [4-6], however, recent studies have indicated that attempts to improve energy efficiency are falling short of expectations [5-7]. Among several causes that contribute to the mismatch between the design and operational building energy performance, two of the most important are misfocused quality management criteria and the high prevalence of quality defects [3, 7, 8]. Studies measuring the thermal performance of UK dwellings, concluded that the whole fabric U-value was 60% greater than the designed target, caused by discontinuity of the insulation layers, due to poor workmanship management [9]. It was also found that the average air permeability measured was 133% higher than desired, due to the existence of defects in the dwellings' fabric [10]. The authors of this paper acknowledge that the UK construction industry is not short of quality management processes, but I argue that the established systems prioritize other issues above energy performance, with the result that preventive procedures and corrective measures that could improve thermal performance are not being enacted. The analysis undertaken for this paper draws on evidence collected from a number of Housing Association (HA) case studies. The HA case studies were chosen because, the UK HA sector accounts for 18% of new domestic housing construction and, in a recent study on energy performance, the sector expressed an interest in improving the energy efficiency of its housing stock [5, 6, 10].

2. Previous related work

In recent decades there has been a continuous effort by the construction industry to apply quality management knowledge acquired from manufacturing and other industrial sectors to improve performance [11]. However, the ultimate quality of buildings is not often in accordance with the specification, with insufficient attention from Quality Management Systems (QMS) towards defects affecting the energy performance of buildings [3, 9]. Implementing QMS in the construction sector has often proved challenging. The obstacles emerge from the nature of the construction industry itself, where projects are implemented in unique circumstances and include a high level of organizational and technical complexity [3, 12, 13]. Many standardized QMS, such as ISO 9001 [14] and PMBOK [15] have been deployed by the construction sector, in order to obtain higher quality levels. However, some authors have questioned the compatibility of standardized QMS within the construction sector [16], suggesting that such solutions often do more harm than good, by introducing excessive bureaucracy and lacking focus on specific issues that vary from project to project.

Issues that the construction industry has yet to master include the understanding that the consistency of QMS outcomes are closely related to a successful identification of a project's core requirements and quality objectives within the quality planning stage [13,17]. Construction projects often fail to identify the project's core requirements and quality objectives, thus impeding the progress of following stages of the quality management process, namely quality assurance, quality control and continuous improvement. Furthermore, the construction industry has yet to fully appreciate that project quality plans should be part of the working packages in the tendering process of the project, in order to allow the bidders to fully understand which quality requirements need to be achieved and how to comply with the requirements in terms of content, format and appropriate timing [18]. As a consequence, all too often conflicts of interests occur when project quality requirements are established solely by the main contractor on construction projects, without the active participation of the clients [16]. For the construction industry to address quality management issues, a better understanding of the framework needed for an effective QMS planning must be developed. Established research has shown that such a framework should include five key elements [17, 18, 19]:

i. Defined Quality Requirements – defining the quality requirements refers to the definition of the quality objectives, based on the criteria of clients, occupants, statutory authorities and regulators.
ii. A Quality Risk assessment - The risk assessment process aims to identify threats and opportunities that may impact in the achievement of the defined quality requirements. It should explore managerial and technical issues involved in the generation of recurrent quality defects identified and recorded in previous projects. As a result,

it establishes priority in terms of addressing to major risks and set guidelines for prevention of undesired non-conformances.

iii. Quality Resource Assessment - The quality resources assessment will explore the provision of essential resources to implement the QMS, establishing roles and responsibilities among the project participants as well as the financial or/and external support to undertake the quality management procedures

iv. Definition of Quality Metrics - The quality metrics element is an operational definition that describes, in specific terms, the quality requirement attributes (under the energy performance of buildings perspective, it could be the desired air permeability rate or number of defects identified in the air control layer, for instance). It also defines how the quality control process will assess these attributes, defining sampling approaches, milestones for monitoring and checking procedures.

v. Quality Compliance Procedures - The quality compliance procedures aims to define how the monitored quality attributes and the achievement of quality requirements will be reported and communicated to the participants, setting procedures for the analysis of the results which will help to formulate corrective actions and possible improvements for the following processes within the project and for the subsequent projects.

Even though the theoretical basis for effective quality planning is well established, actual quality management practice in the construction industry fails to deliver expected outcomes because if focuses on mitigating visual defects, which are likely to raise warranty claims and cause occupant dissatisfaction in the short term [3, 20]. Of particular relevance for this paper, defects that impair the ability of buildings to achieve the expected thermal performance quality criteria, such as the discontinuity of the insulation layer or gaps in the vapor/air barrier which allow undesired air permeability, are mostly ignored [3]. According to recent studies [5, 10], the impact of defects on the energy performance of buildings cannot be ignored. Bell et al. [10] found that the overall heat loss in new-build homes in the UK was 54% higher than predicted, often due to poor installation of the buildings fabric. Similarly, NEF's report on energy performance of social housing projects [5] indicated that up to 67% of buildings surveyed failed to meet the expected external walls U-values and air permeability rates. In both studies, the most common defects deemed responsible for the undesired heat loss and consequent increase of space heating energy use were lack of continuity of the insulation layer, gaps in the air/vapor control barriers and thermal bridging especially through window lintels. With that research in mind, this paper will investigate how quality management systems in the UK domestic housing sector, focusing on energy performance, are planned and implemented and assess how quality management system enhancements could applied to reduce energy demand.

3. Methodology

A qualitative approach with a particular emphasis on grounded theory [16, 17] was employed to identify the keys aspects related to how the QMS implemented by HAs addressed issues related to the energy performance of buildings. In accordance with the requisites for a qualitative research methodology, data was collected from different sources (quality assurance documentation, observation of project meetings, project site visits and semi-structured interviews with the projects' stakeholders). The aim of the data collection activity was to reveal obstacles and challenges that arise in the process of planning and implementing a QMS that focused on building energy performance. The initial data was broken down and coded, to reveal correlations with the QMS theoretical framework. A further iteration of coding process was conducted to group data in relation to key concepts, which in turn were aligned with the phenomena that this study set out to explore. The final step of the investigation process examined the relationships between data clusters, to reveal challenges and opportunities encountered by HAs in the process of managing quality issues related to energy performance of buildings. Data was collected from four case study construction projects pertaining to two HAs located in the South West of the UK.

- Case study 1 - Involved the construction of 28 housing units and was procured under a traditional route where the contractor had no participation in the strategic brief nor in the design process.
- Case study 2 - Included the construction of 39 dwellings and the preferred procurement route was design and build.
- Case study 3 - Comprised the construction of 67 housing units and procurement route was design and build.
- Case study 4 - Involved the construction of 72 dwellings and the chosen procurement route was design and build.

4. Results

The results of each case study are presented in accordance with the five elements of the QMS theoretical framework. In terms of the requirements which are related to the energy performance of buildings, case studies 1, 2 and 3 aimed to comply with UK building regulations, Part L1A "Conservation of fuel and power in new dwellings" [18]. Case study 4 presented a set of requirements that aimed to achieve Passivhaus accreditation [19]. In relation to the risk assessment process, case studies 1, 2 and 3 analyzed information from a defect database which was managed by the HA and was fed by occupant complaints arising from the post-occupation stage of in-use dwellings. In addition, the risk assessment process was complemented by inputs from project managers working for the HA and the main contractor (except for case study 1 where the procurement followed a traditional route). In case study 4, as this was the first project to aim for Passivhaus accreditation in the HA, an accredited consultant was hired by the client to provide project participants with a list of quality issues to be addressed during the quality planning and design stages.

As per the necessary resources to implement the quality programme, in case studies 1 and 2 a decentralized approach was used. The HA deployed a quality officer on its behalf to perform quality inspections on weekly basis. The contractor required the site manager to proceed with quality inspections whenever trade gangs have completed their activities and request permission to work in another housing unit. Additionally, an independent building surveyor company was commissioned to administer the snagging process once the dwellings are deemed completed. Moreover, an external company was contracted to perform the air pressure tests as required by the building regulations. The procedures adopted by case study 3 were very similar to case studies 1 and 2, except by the fact that the snagging process is to be conducted by HA's quality officer and the project manager. In respect to case study 4, the approach towards quality management was different from the other case studies. As the project requirements and quality objectives in relation to energy performance targets were clear in the contract documentation as a responsibility of the major contractor, a centralized approach for quality assurance was adopted. The major contractor deployed a dedicated quality champion which was responsible to overview the workmanship in specific building fabric elements and junctions as acknowledged in the risk assessment stage. In addition, a company was commissioned for the pressure tests which would take place in different stages of the construction process.

In terms of the quality metrics, case studies 1, 2 and 3 were oriented to comply with the energy performance attributes set by the building regulations (e.g. minimum dwelling overall U-value as well as for specific building elements; maximum air permeability rate and carbon emission rates). The compliance to the minimum performance standard set by the building regulations were confirmed during the design stage through SAP (standard assessment procedure) calculations [18]. The air permeability rates are to be confirmed by actual performance through air pressure tests once the dwellings are deemed completed on a sampling basis of three units or 50% of each dwelling type, whichever the less as oriented by the building regulations. In respect to quality control, in case study 1, 2 and 3 the procedures undertaken by the quality officer working for the HA comprehend weekly assessments through the use of a standardized report templates which present a structure to collect data related to the construction stage progress but does not systematize the collection of defects which could potentially affect the thermal performance of dwellings. In relation to the procedures used by site managers in case studies 1, 2 and 3, standard checklists are used for quality checking whenever trades activities are deemed completed. These quality checklists present, to some extent, items which are related to the energy performance of the dwellings, such as checking for proper sealing around pipework penetrations through the building fabric, however their far from covering at least the most frequent defects which affect the thermal behavior of the dwellings. In most of the cases, and it includes the snagging process as well, the defect identification relies on the experience and the level of awareness of the professionals involved in quality control towards this type of defects.

In case study 4 the quality metrics in regard to the building envelope thermal performance were defined by the Passivhaus standard (e.g. building components' U-values, thermal bridging through structural elements and air permeability). The thermal performance attributes were analyzed and their compliance confirmed through the Passivhaus Planning Packages (PHPP) [19] during the design stage, except for the air permeability rate which should be confirmed through air pressure tests. This tests will take place in the housing units in different stages of the construction process, in order to make it easier to identify in which element of the building envelope defects might have taken place and appoint the appropriate trade to proceed with corrective measures. It was defined that the air tests should be performed just after the installation of the vapor barriers and closures (windows and external doors), after plumbing and electrics first fix but prior to plaster boarding, after first fix, and a final test when the dwellings are deemed completed. The dedicated quality champion should proceed the quality control procedures on daily basis, supported by checking lists which encompass the potential defects input by the consultant in the risk assessment stage and the core components of the Passivhaus Project Management Checklist (i.e. insulation installation, wind tightness, airtightness, services and builders work)[19].

In respect to quality compliance, the case studies which aim to fulfil the requirements of the building regulations must demonstrate to the Building Control Bodies (BCB) that the housing units, as constructed, meet the targets of fabric energy efficiency and carbon emission rates. According to the approved document Part L1A [18], "the builder should demonstrate to the BCB than an appropriate system of site inspection is in place to give confidence that the construction procedures achieve the required standard of consistency". In that sense, the contractor provides the BCB with the regular quality reports, in addition to the results of the air pressure tests. In case study 4 the compliance process encompasses the design and construction stages and the achievement to Passivhaus standards should be verified by an independent certifier other than the consultant involved in the project. The design and the PHPP documentation must be signed off by the accredited consultant. In order to provide evidence that the workmanship meets the PHPP and design specifications, a final summary report containing signed off checking lists, key stages photographic evidence according to the core components of the Passivhaus Project Management Checklist and the results of the air pressure tests.

Despite the many quality procedures in place in case studies 1, 2 and 3 the evidence collected during site visits shows that the occurrence of defects with potential to undermine the thermal performance of the dwellings are common, as illustrated by Fig. 01.

Fig. 1. (a) Ill-fitted insulation; (b) Rupture in vapor control barrier and displacement of insulation layer; (c) Discontinuity of insulation.

5. Discussions

The results obtained from case studies 1, 2 and 3 confirm that the deployed quality management procedures did not systematically the appraise quality defects which had the potential to compromise the thermal performance of building fabrics, focusing instead on visible cosmetic defects [3, 20]. In line with findings by Landin [21], project participants of case studies 1, 2 and 3 adopted their own quality management procedures, which they saw as fit to achieve the desired quality requirement of clients and occupants. Even though the building regulations set out energy performance requirements and attributes to be pursued, the required compliance methodology was subjective when it came to the construction phase resulting in non-structured compliance procedures. By way of contrast, in case study 4 the requirements and compliance methodology set by the Passivhaus standard were clear from the beginning and were defined even before the procurement process. As predicted by Juran [22] and Jraisat [13], the early definition of requirements and compliance procedures was found to have helped in the development of consistent and systematic quality management process. Analyzing the relationship between the elements of the QMS theoretical framework, two categories emerge as important to achieve expected outcomes – requirements and compliance. Without the proper definition of both categories, the quality management process lacked objectivity and efficacy. As an example, when assessing quality resources requirements, case studies 1 and 2 were found to have deployed at least four different overlapping quality control procedures, all of them lacking focus on quality issues related to building energy performance. Quality control tools were also found to ineffectively systematize the classification of defect types during the construction process and consequently many defects still remained unidentified and uncorrected as the projects progressed. Such outcomes were judged to be a direct consequence of the compliance methodology proposed by the

UK building regulations, which does not require a compulsory and extensive set of quality data from building contractors, such as that specified in the Passivhaus standard.

6. Conclusions

This paper sets out to investigate how quality management systems in the UK domestic housing sector, focusing on energy performance, are planned and implemented and assess how quality management system enhancements could be applied to reduce energy demand. The study reveals that, even though several quality control procedures may be applied, the achievement of quality criteria regarding the thermal performance of buildings can still be uncertain. The results also suggest that the consistency of QMS depends on the objective definition of the quality requirements (e.g. thermal performance attributes) and specially the establishment of a robust quality compliance procedure. Undeniably, the quality compliance process is part of the major contractor's scope of work, however, the definition of how the compliance to the quality criteria is to be administered and demonstrated, must be defined by the HAs. Relying solely in the quality compliance determined by the building regulation is not sufficient to achieve the desired energy performance. In that sense, the authors propose that HAs should incorporate thermal performance quality compliance criteria in their own quality management policies, by setting objective and measurable quality standards and outcomes, as well as defining which and when specific building elements should be monitored, tested and its quality demonstrated. If these findings are enacted by HAs, they could contribute to reduce space heating requirements in UK domestic housing stock, by helping to mitigate the well-known contribution of defects to the building's energy performance gap.

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References

[1] DECC. Digest of United Kingdom Energy Statistics 2015. 2015.
[2] DECC. Energy consumption in the UK, Overall data tables, 2015 Update. Department for Energy and Climate Change; 2015.
[3] Tofield B. Delivering a Low-Energy Building: Making Quality Common Place. (Build with CaRe report). University of East Anglia, Norwich; 2012.
[4] Cohen R, Bordass B. Mandating transparency about building energy performance in use. Building Research & Information. 2015;43:534-52.
[5] NEF. Insights from Social Housing Projects - Building Performance Evaluation Meta-Analysis. Executive Report Innovate UK: National Energy Foundation; 2016.
[6] Palmer J, Godoy-Shimizu D, Tillson A, Mawditt I. Building Performance Evaluation Programme: Findings from domestic projects - Making reality match design. Innovate UK; 2016.
[7] Zero Carbon Hub. Closing the gap between design and as-built performance, End of term report. 2014.
[8] CIOB. What's happening to our quality control? Magazine of the Chartered Institute of Building. http://www.constructionmanagermagazine.com/agenda/whats-happe7ning-our-qu6ality-co9ntrol/2016.
[9] Johnston D, Miles-Shenton D, Farmer D. Quantifying the domestic building fabric 'performance gap'. Building Services Engineering Research and Technology. 2015.
[10] Bell M, Wingfield J, Miles-Shenton D, Seavers J. LowCarbon Housing: Lessons from Elm Tree Mews. York; 2010.
[11] McIntyre C, Kirschenman M. Survey of TQM in construction industry in upper Midwest. Journal of Management in Engineering. 2000;16:67-70.
[12] Kanji GK, Wong A. Quality culture in the construction industry. Total quality management. 1998;9:133-40.
[13] Luai Jraisat, Lana Jreisat, Christine Hattar. Quality in construction management: an exploratory study. International Journal of Quality & Reliability Management. 2016;33:920-41.
[14] BSI. BS EN ISO 9001:2015. Quality management systems Requirements: British Standards Institution; 2015.
[15] Project Management Institute. Project Management Body of Knowledge (PMBOK® GUIDE). 4th Edition ed2001.
[16] Corbin JM, Strauss AL. Basics of qualitative research : techniques and procedures for developing grounded theory. 3rd ed. ed. Thousand Oaks, CA : London: Thousand Oaks, CA : London : SAGE Publications; 2008.
[17] Bryman A. Social research methods. 4th ed. ed. Oxford ; New York: Oxford ; New York : Oxford University Press; 2012.
[18] Government H. Part L1A - Conservation of fuel and power. 2013.
[19] BRE. The Passivhaus Standard. 2016.
[20] Auchterlounie T. Recurring quality issues in the UK private house building industry. Structural Survey. 2009;27:241-51.
[21] Landin A. ISO 9001 within the Swedish construction sector. Construction Management and Economics. 2000;18:509-18.
[22] Juran JM. Quality Planning and Analysis. 3rd ed. ed: McGraw; 1993.